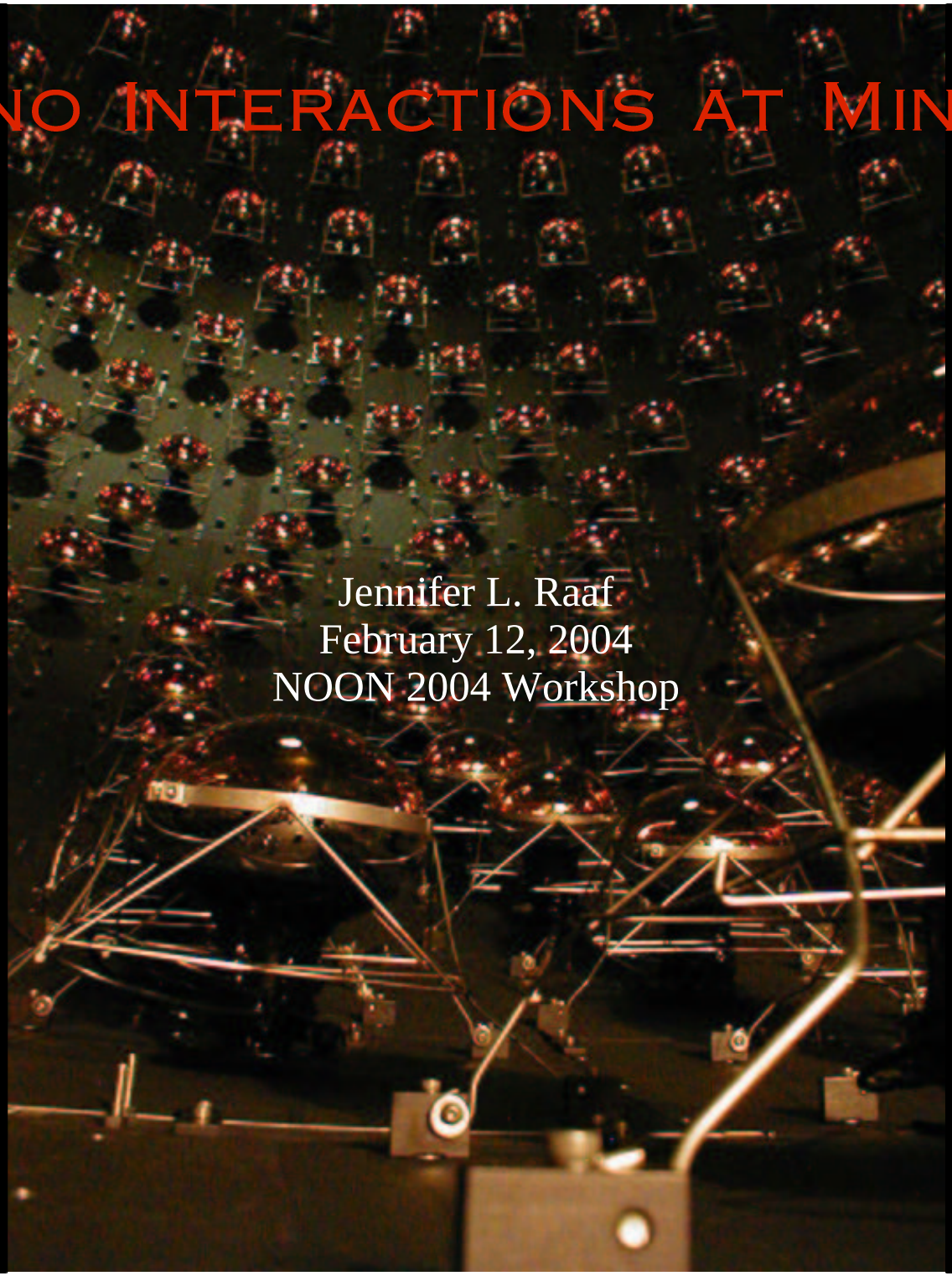
Neutrino Interactions at MiniBooNE



Jennifer L. Raaf
February 12, 2004
NOON 2004 Workshop

Overview

MiniBooNE
- Beam and Detector
- Event Reconstruction and Particle ID
- Calibration and Neutrino Data

Data/MC Comparisons
- Charged current quasi-elastic events
- Neutral current π^0 events
- Neutral current elastic events

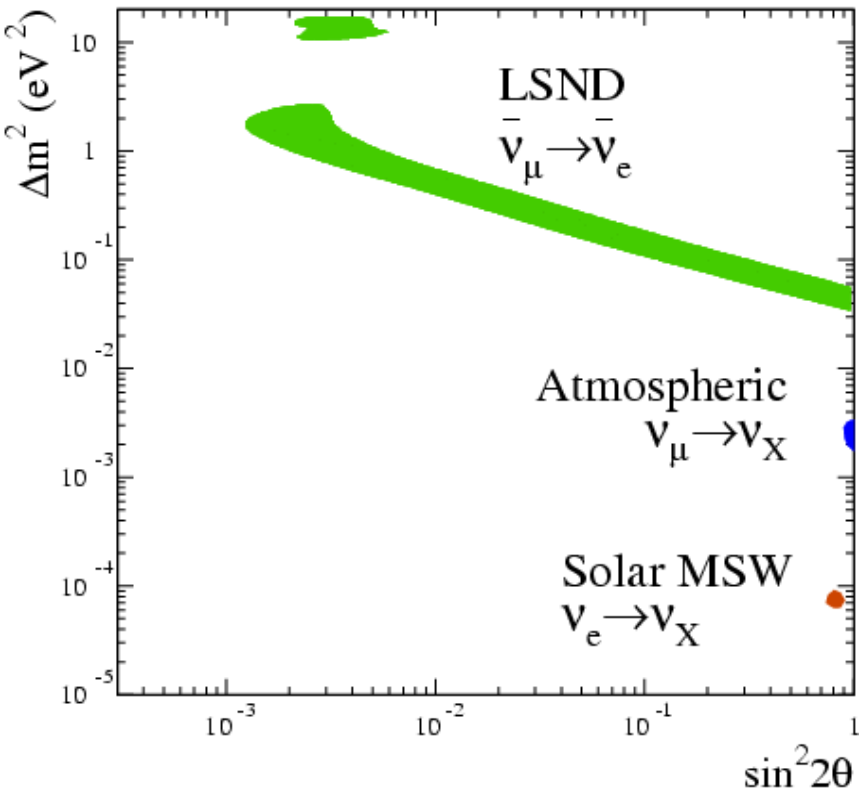
Conclusions

MiniBooNE Motivation

LSND: 3.8σ $\bar{\nu}_e$ excess from $\bar{\nu}_\mu$ source

Oscillation probability:
(0.264 ± 0.067 ± 0.045)%

As yet unconfirmed....



Oscillation physics:
MiniBooNE will check the LSND result with similar L/E,
higher statistics, and different systematics for the ν flux and particle ID

Non-oscillation physics:
- Charged current quasi-elastic
- Neutral current π^0
- Neutral current elastic scattering

BooNE Collaboration

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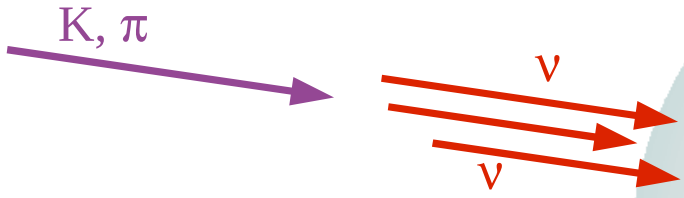
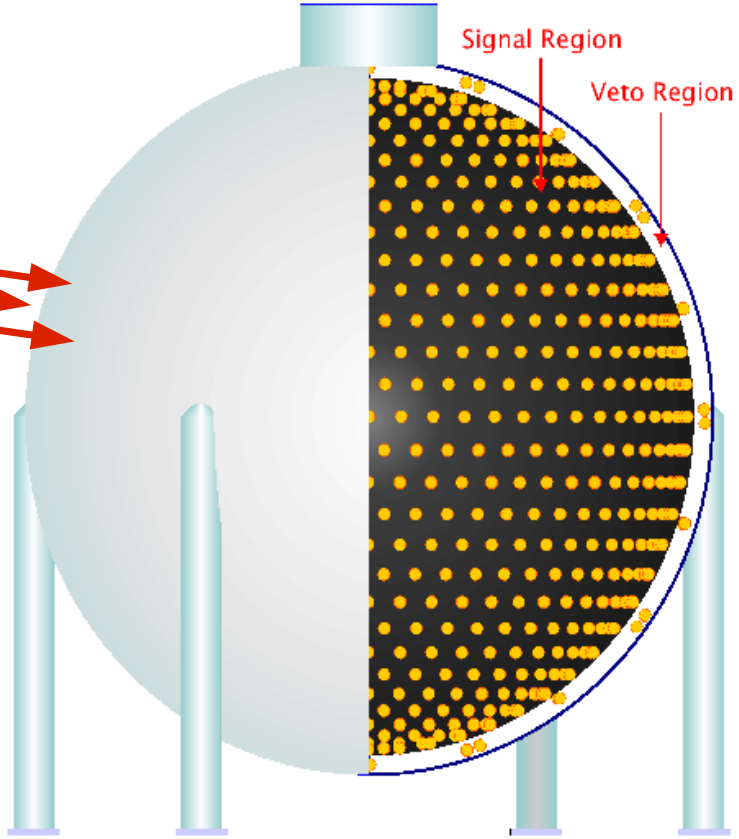
BooNE Beam & Detector

Beam

- 8 GeV protons from the Fermilab Booster
  directed into horn containing 71 cm Be target
- Secondary particles from target interactions (π, K) focused into 50 m decay region ($\pi \rightarrow \mu\ \nu_\mu$)
  Absorber and 450 m of dirt "clean" the beam of everything except ν's



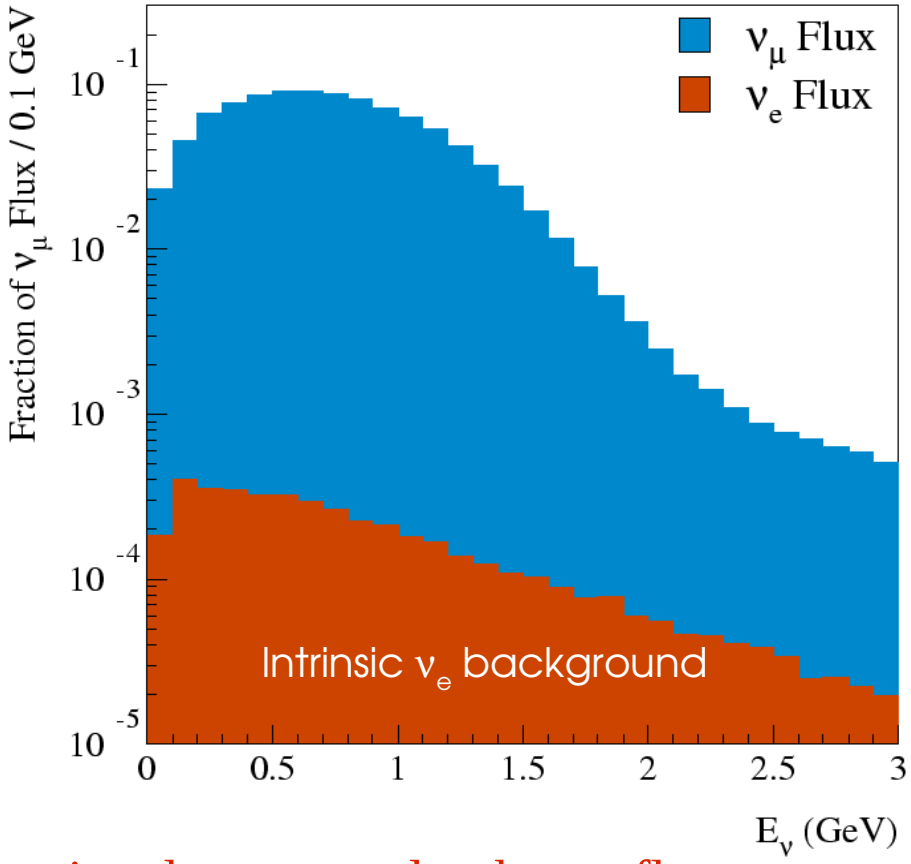


Detector

- 12 m diameter sphere
- 8 inch Hamamatsu PMT's
- 1280 PMT's in signal region (10% coverage)
- 240 PMT's in veto region
- ~800 tons pure mineral oil

Beam Composition

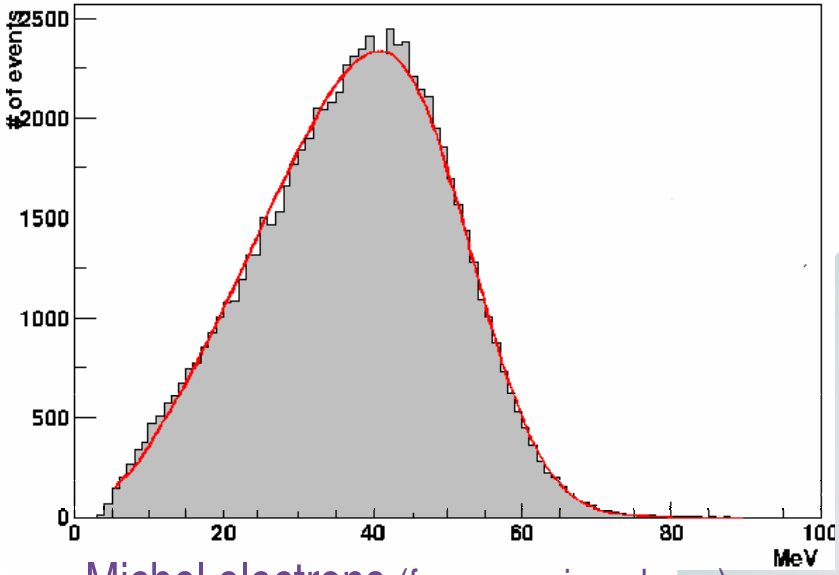
- protons on beryllium
  $p + Be \rightarrow \pi^+, K^+, K^0_L$
- yield a high flux of ν_μ
  $\pi^+ \rightarrow \mu^+ \nu_\mu$
  $K^+ \rightarrow \mu^+ \nu_\mu$, $K^0_L \rightarrow \pi^- \mu^+ \nu_\mu$
- with a low ν_e background
  $\mu^+ \rightarrow e^+ \nu_e \bar{\nu}_\mu$
  $K^+ \rightarrow \pi^0 e^+ \nu_e$, $K^0_L \rightarrow \pi^- e^+ \nu_e$



ν_e background comparable to oscillation signal $\rightarrow$ need to know flux very well!!

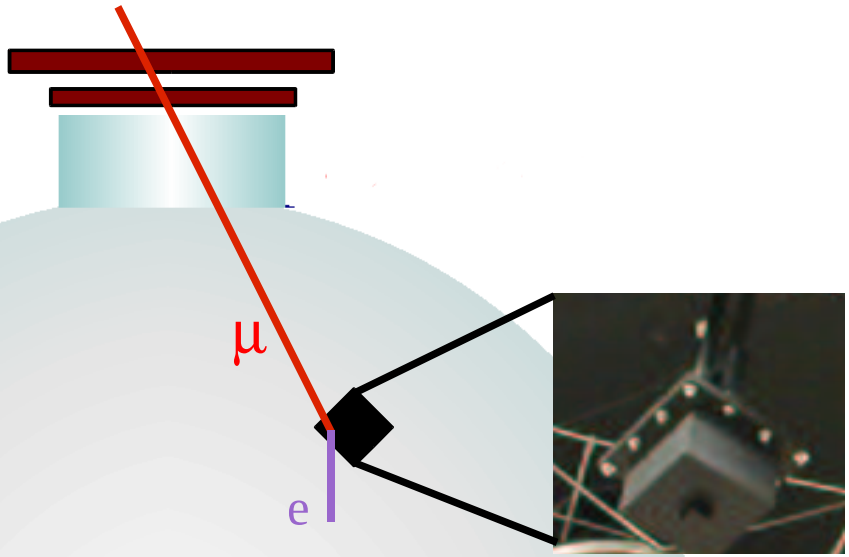
- detailed simulations (GEANT3/GEANT4)
- CERN HARP measurements with MiniBooNE target replica
- BNL E910 production data with thin Be target
- Off-axis muon counter (LMC) $\rightarrow$ background ν_e's from K decays
- 25/50 meter decay region $\rightarrow$ background ν_e's from μ decays

Detector Calibration



Michel electrons (from cosmic μ decay)

Known energy spectrum between 0 and 52.3 MeV
Fix detector energy scale
Energy reconstruction accuracy: 14.8% at 52.3 MeV



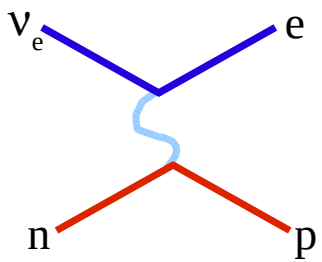
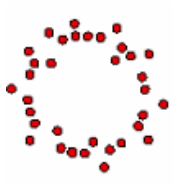
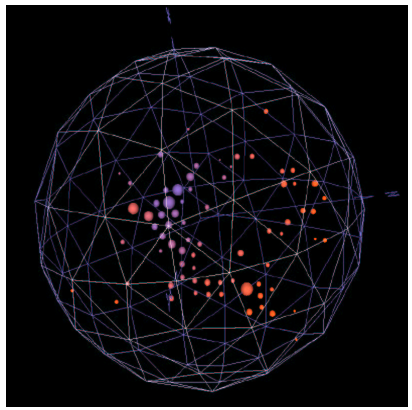
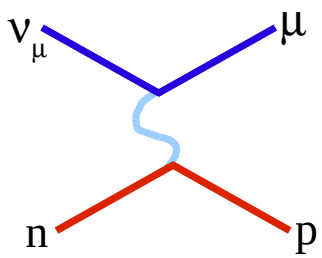
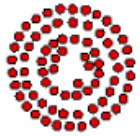
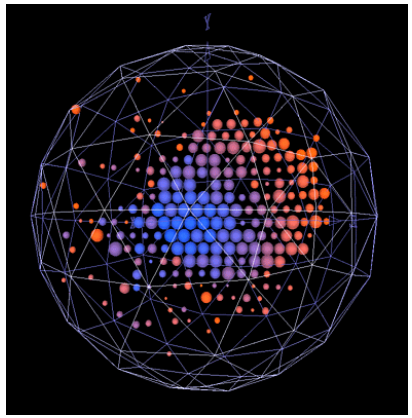
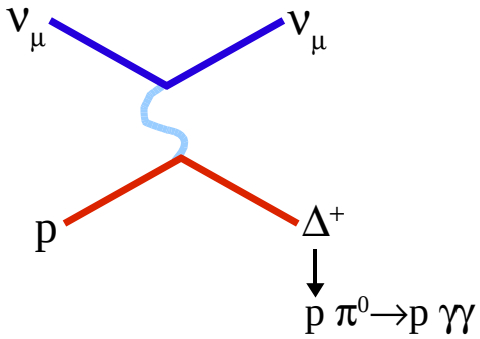
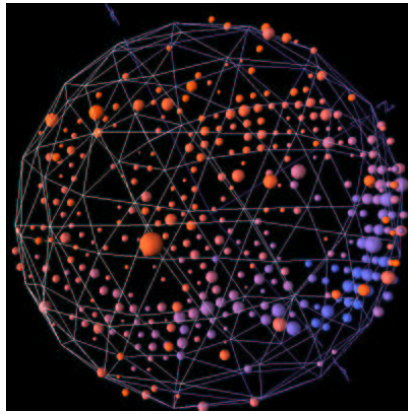
7 Scintillator cubes

Optically isolated from oil
Detect stopping cosmic μ
Path length from muon hodoscope
Independent measurement of
muon energy up to 400 MeV

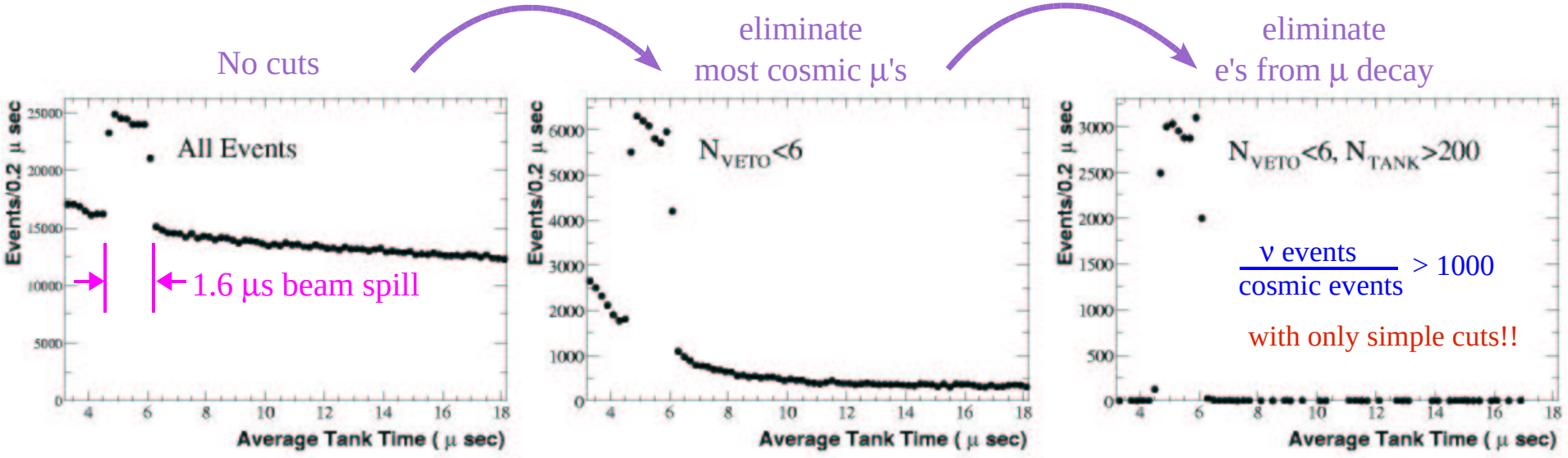
4 Laser flasks

Known wavelength and intensity
Hit reconstruction:
PMT time/charge resolution
pre/after-pulsing
Oil optical properties:
attenuation, scattering,
surface reflections

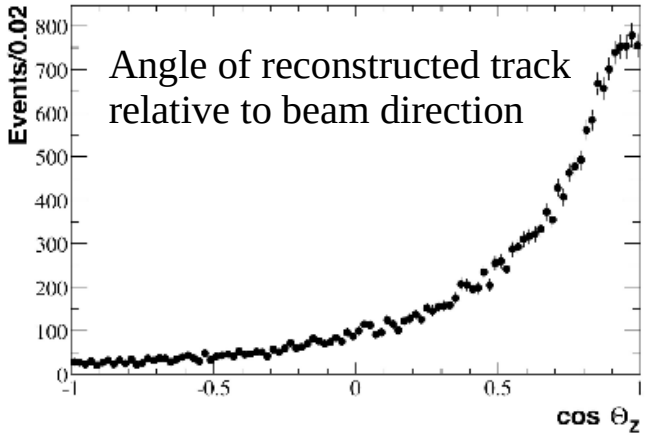
Particle Identification

	Veto Activity	Track Extent	Ring Profile	Hit Topology
	no			
	possible			
	no			

Beam Neutrino Events



- Beam sent to MiniBooNE in 1.6 μs wide spills
- DAQ triggers on FNAL Booster signal 4.6 μs before beam reaches target
- 19.2 μs window recorded surrounding each spill

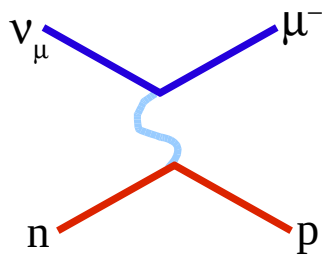


So far....

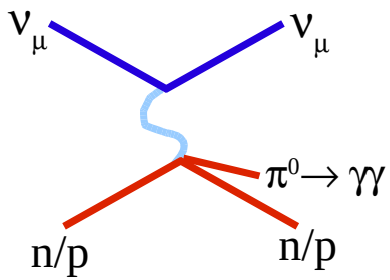
204,000 ν_μ events from 1.8×10^{20} protons on target

Early Physics

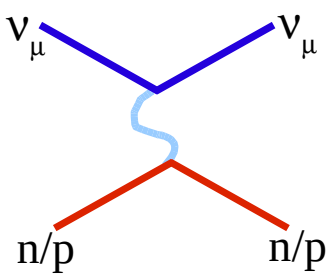
Charged Current
Quasi-Elastic scattering
(CCQE)



Neutral Current
π^0 production
(NC π^0)

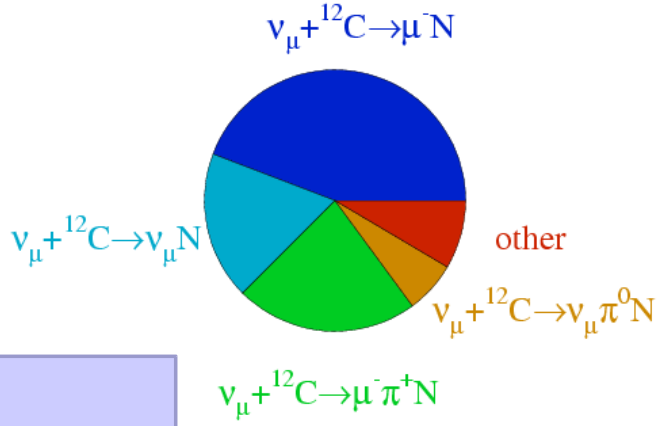


Neutral Current
Elastic scattering
(NCE)



At MiniBooNE energies:

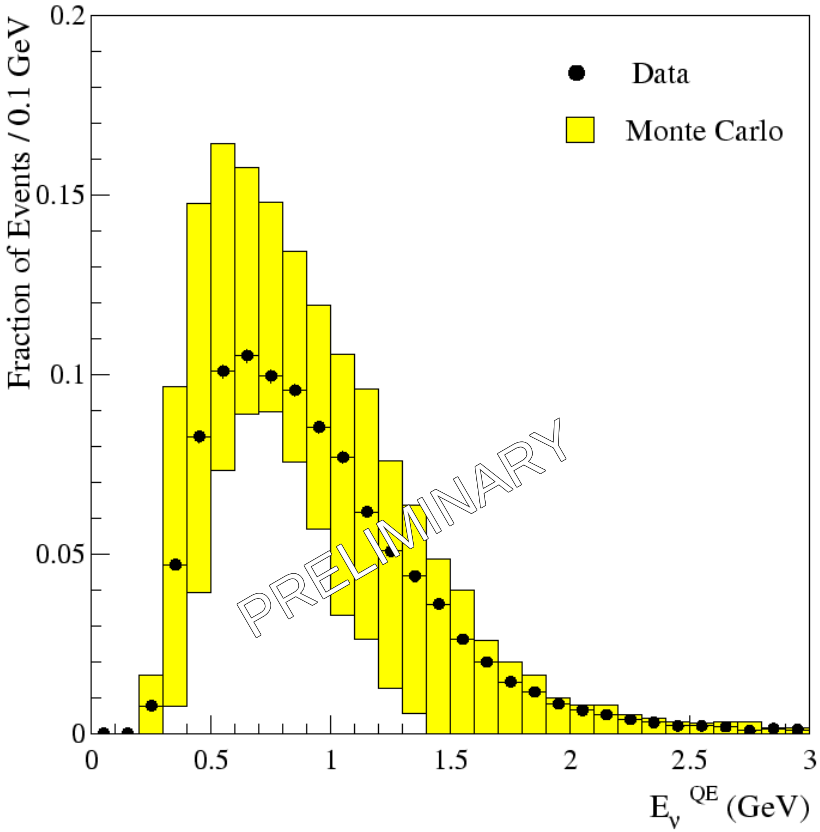
Charged current quasi-elastic:	39%
Neutral current π^0 production:	7%
Neutral current elastic:	17%



- ν_μ interactions only
- ~10^{20} protons on target analyzed
- Data/MC comparisons relatively normalized
- Systematic uncertainties are preliminary

Charged Current Quasi-Elastic Scattering

- ν_e CCQE events with similar kinematics are main signal for $\nu_\mu \rightarrow \nu_e$ oscillation search
- MiniBooNE is sensitive to ν_μ disappearance for $\Delta m^2 \sim 0.1\text{-}10\ eV^2$
  reconstructible ν_μ energy and reasonably well-known cross section
- Characterize nuclear effects in ν-A interactions at ~1 GeV



Event selection:
single muon-like ν Cerenkov ring
scintillation light consistent with CCQE
high statistics: 30,000 events, 88% purity

Use QE kinematics to reconstruct E_ν from E_μ, $\cos\theta_\mu$
~15% energy resolution

Energy dependence sensitive to ν_μ disappearance

Data show reasonable agreement with MC predictions

CCQE: Q^2 Distribution

Leptonic four-momentum transfer

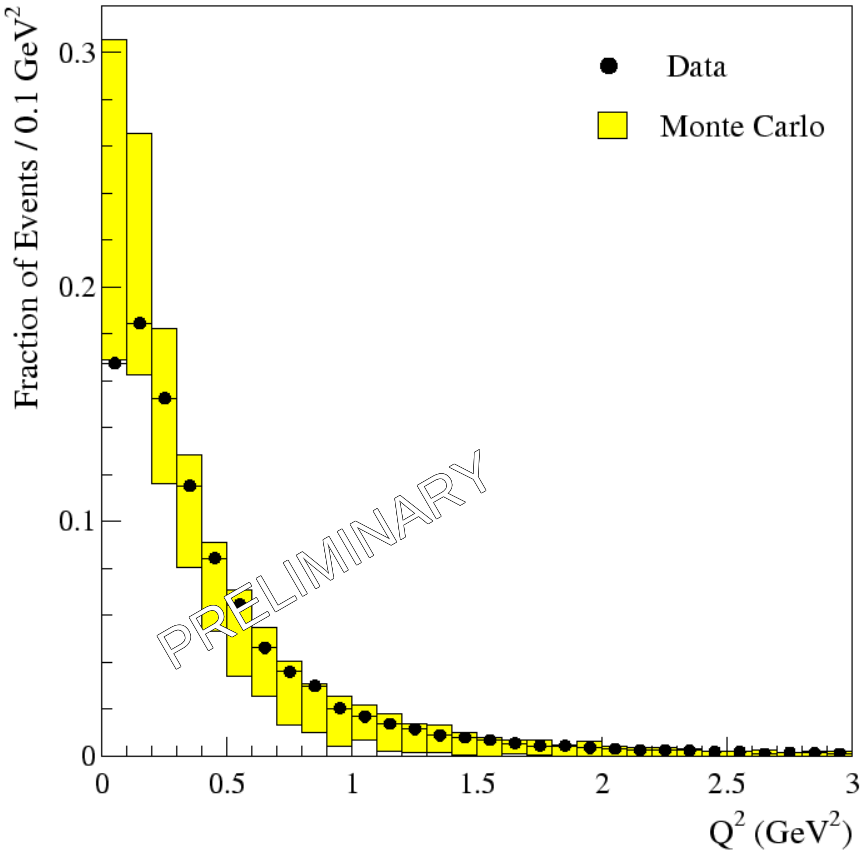
$Q^2 = -(p_\nu - p_\mu)^2$

MC predictions based on Fermi gas nuclear model (NUANCE)

Nuclear effects expected at low Q^2

Hint to more cross section suppression at low Q^2 in data compared to MC predictions

Physics or detector effect?



Low Q^2 suppression also seen in charged-current inclusive distributions in K2K near detectors, on O and Fe targets. (Ishida, NuInt01)

Neutral Current π^0 Production

Background to $\nu_\mu \rightarrow \nu_e$ oscillation search

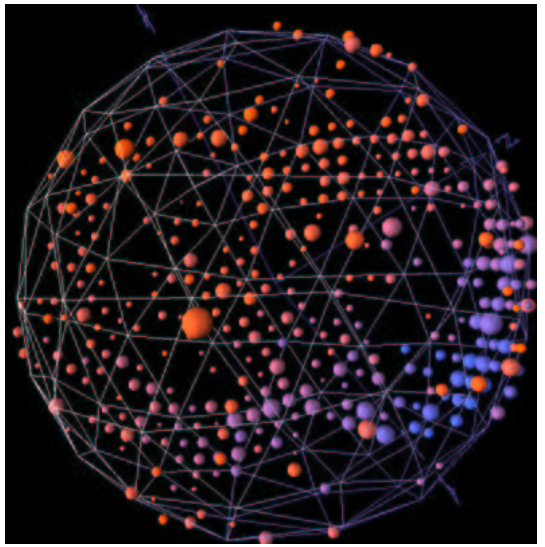
Knowledge of NC π^0 cross section crucial for distinguishing $\nu_\mu \rightarrow \nu_\tau$ from $\nu_\mu \rightarrow \nu_{sterile}$ in atmospheric neutrinos

Total cross section measurement and π^0 angular distribution constrain mechanisms for NC π^0 production

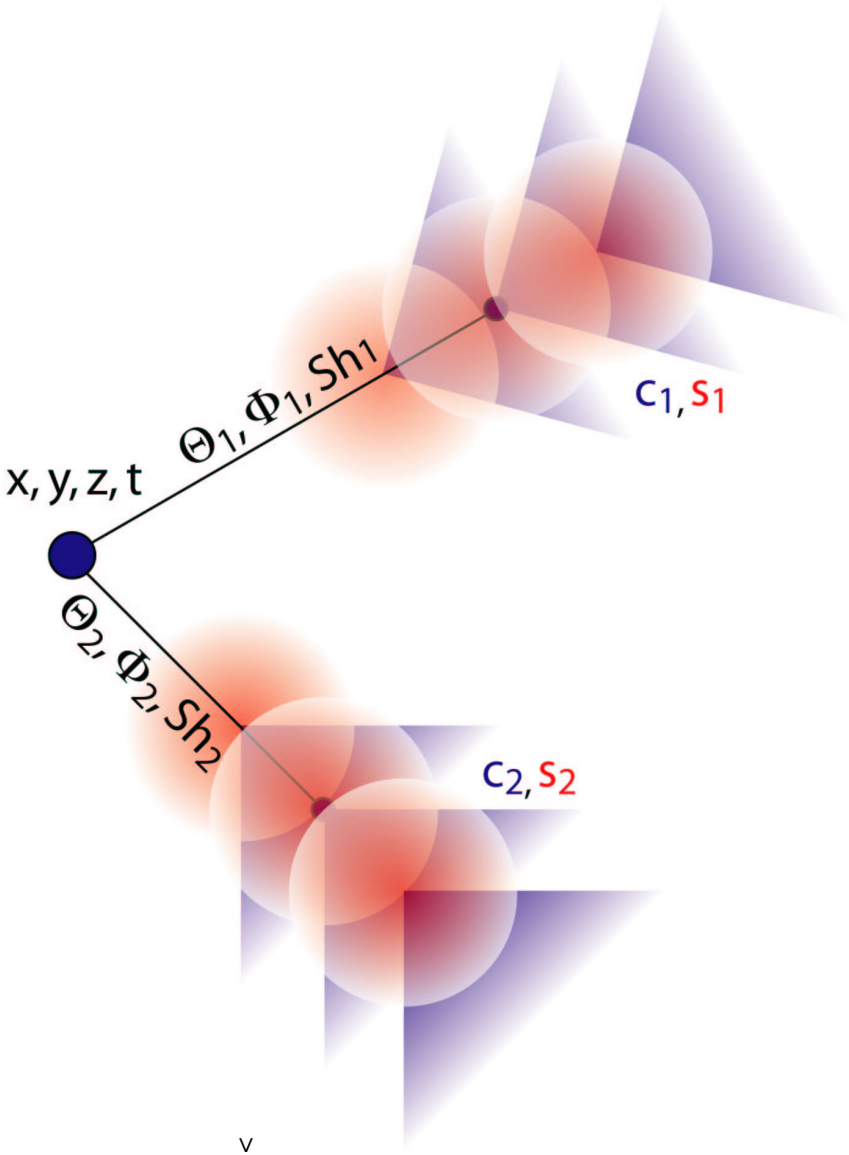
Production mechanisms:

Resonant: Nucleon goes into excited state (Δ,N) and decays by radiating π^0

Coherent: Neutrino scatters from entire nucleus. Nucleus remains in ground state and does not break apart.



NC π^0: Reconstruction



blue = Čerenkov light
red = scintillation light

Fit event assuming two rings (14 parameters)

- decay vertex (4)
- direction of γ's (4)
- mean emission points (2)
- amount of Čerenkov/scintillation light (4)

- no (e/μ) ring ID

Determine event kinematics (using Čerenkov light)

$$mc^2 = \sqrt{2E_1E_2(1-\cos\theta_{12})}$$

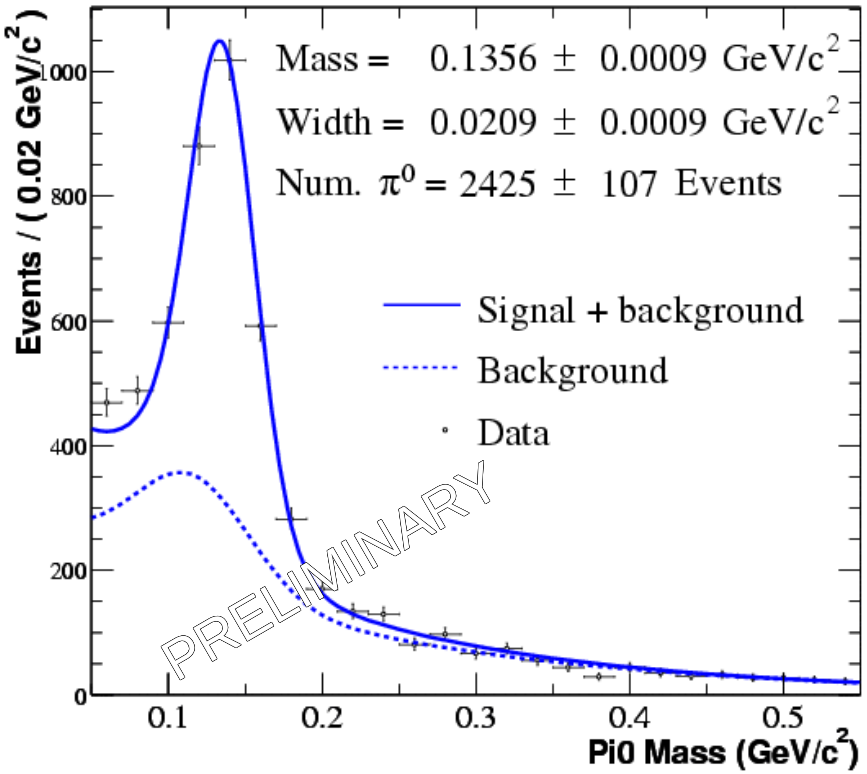
$$\vec{p} = E_1\hat{u_1} + E_2\hat{u_2}$$

$$\beta\cos\theta_{CM} = \frac{|E_1 - E_2|}{E_1 + E_2}$$

NC π^0: Mass Distribution

Event selection from beam triggers:

$N_{TANK} > 200$
$N_{VETO} < 6$
$R < 500$ cm
No decay electrons
$E_{\gamma 1}, E_{\gamma 2} > 40$ MeV



Fitted curves MC-based parameterizations

Background peak near $m_{\pi 0}$ expected
- final state interactions
- multi-pion events

Bin data in kinematic quantities
- π^0 momentum ($p_{\pi 0}$)
- Energy asymmetry ($\beta \cos\theta_{CM} = \frac{|E_1 - E_2|}{E_1 + E_2}$)
- Angle of π^0 relative to beam ($\cos\theta_{\pi 0}$)

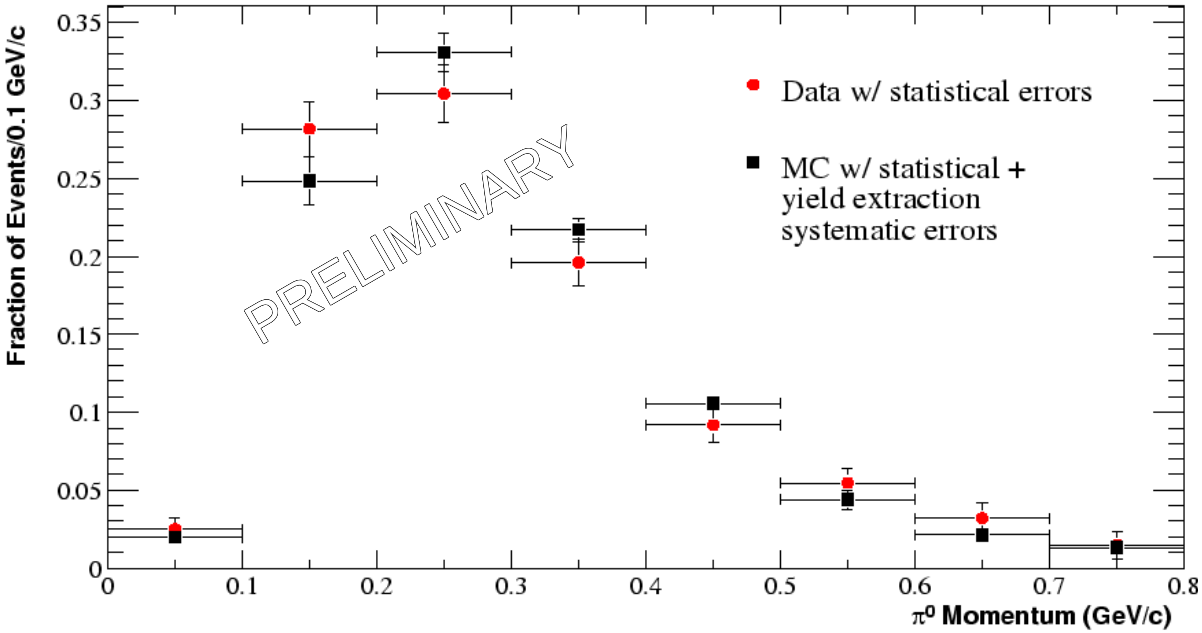
Extract binned yields

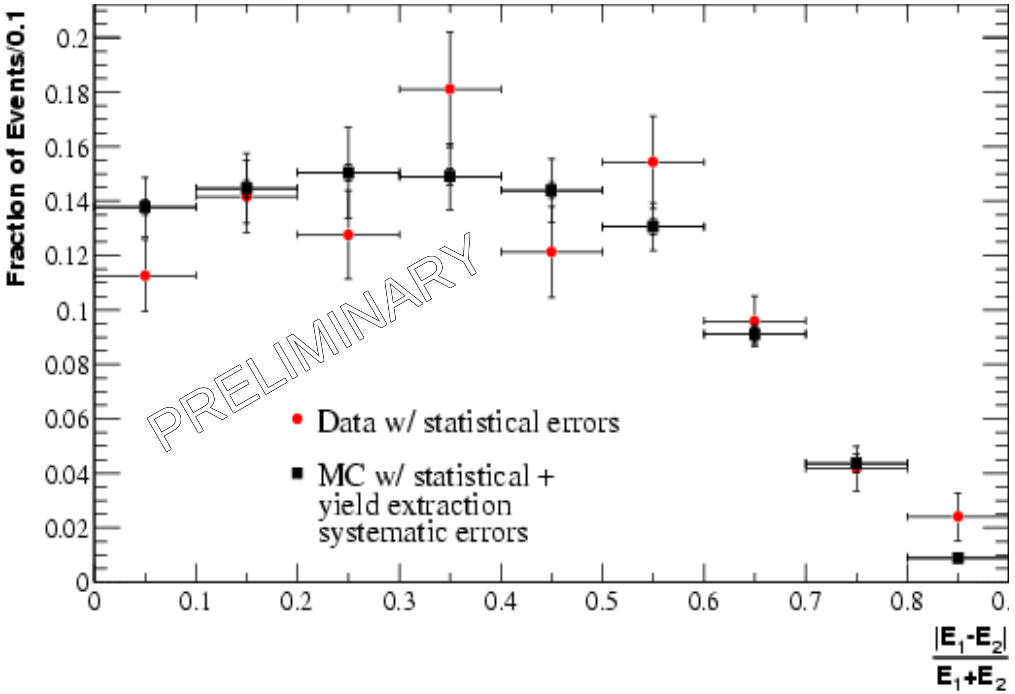
NC π^0: Kinematic Distributions

π^0 momentum

Good data/MC agreement

Fall-off at high momentum due to
- neutrino flux
- $\bar{\nu}$ overlapping $\check{C}$ rings

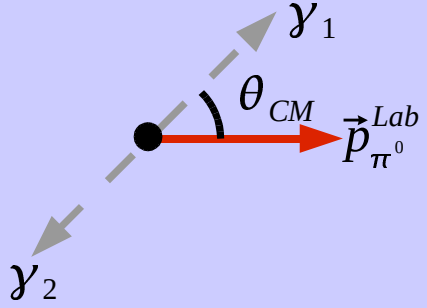




π^0 decay energy asymmetry

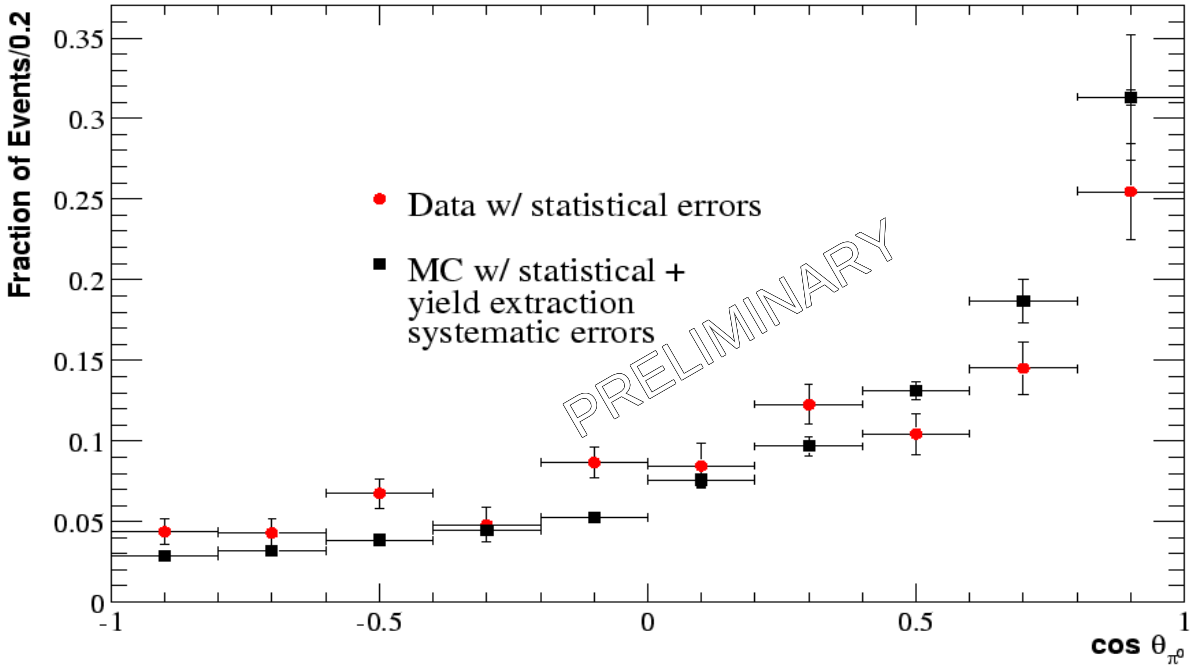
θ_{CM} - angle between π^0 decay axis in CM and π^0 direction in lab

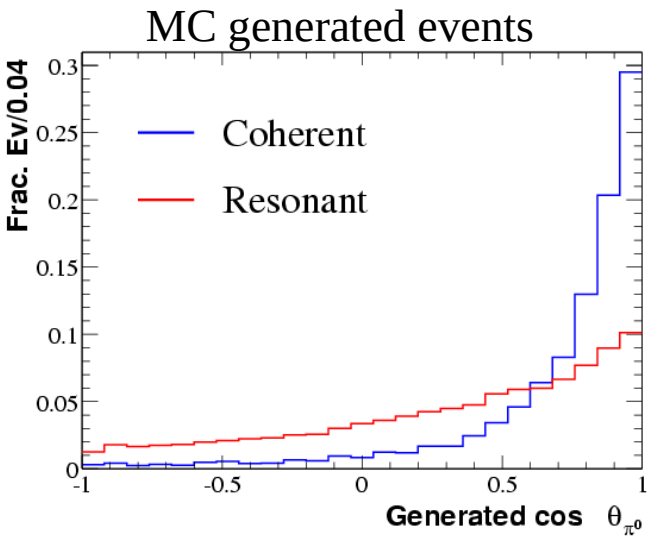
$$\beta \cos\theta_{CM} = \frac{|E_1 - E_2|}{E_1 + E_2}$$



Fall-off due to γ energy cut

NC π^0: Kinematic Distributions





MC assumes Rein-Sehgal cross sections

Recent theories (Paschos, hep-ph/0309148) and experiments (K2K) suggest lower contribution from coherent pion production

MiniBooNE will extract coherent contribution

π^0 lab production angle

sensitive to production mechanism
coherent: forward-peaked
resonant: not as forward

Neutral Current Elastic Scattering

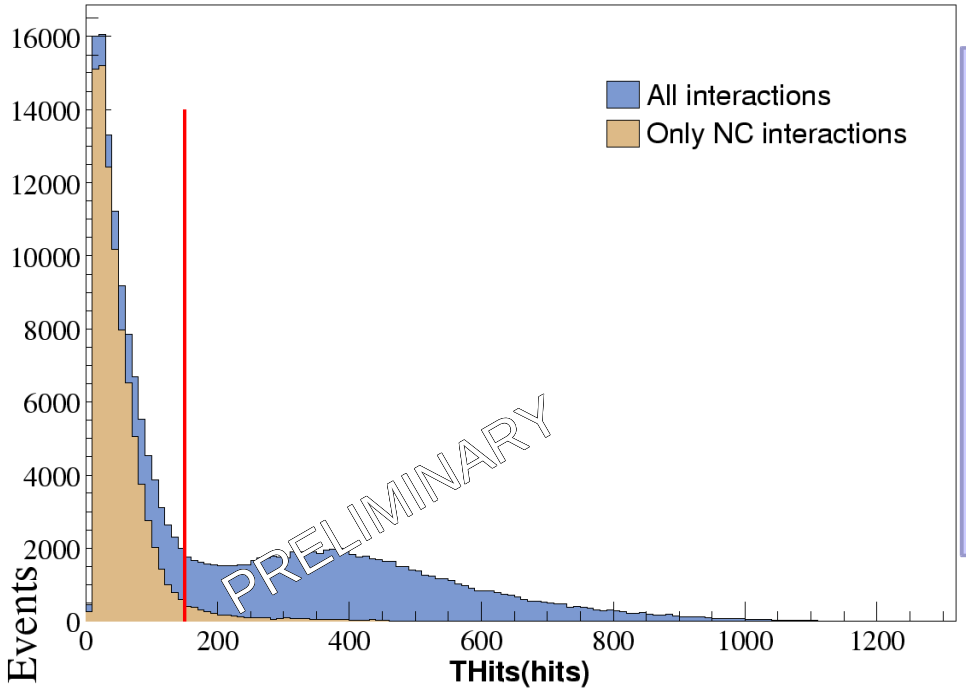
"Nucleon spin crisis"

What carries the proton spin? valence quarks, sea quarks, or gluons?

σ(NCE)/σ(CCQE) ratio probes strange sea contribution to nucleon spin

Measure σ(NCE)

Will help in understanding scintillation light for MiniBooNE oscillation search



$\nu_\mu + (p/n) \rightarrow \nu_\mu + (p/n)$

Typically sub-$\check{C}$: dominated by scintillation

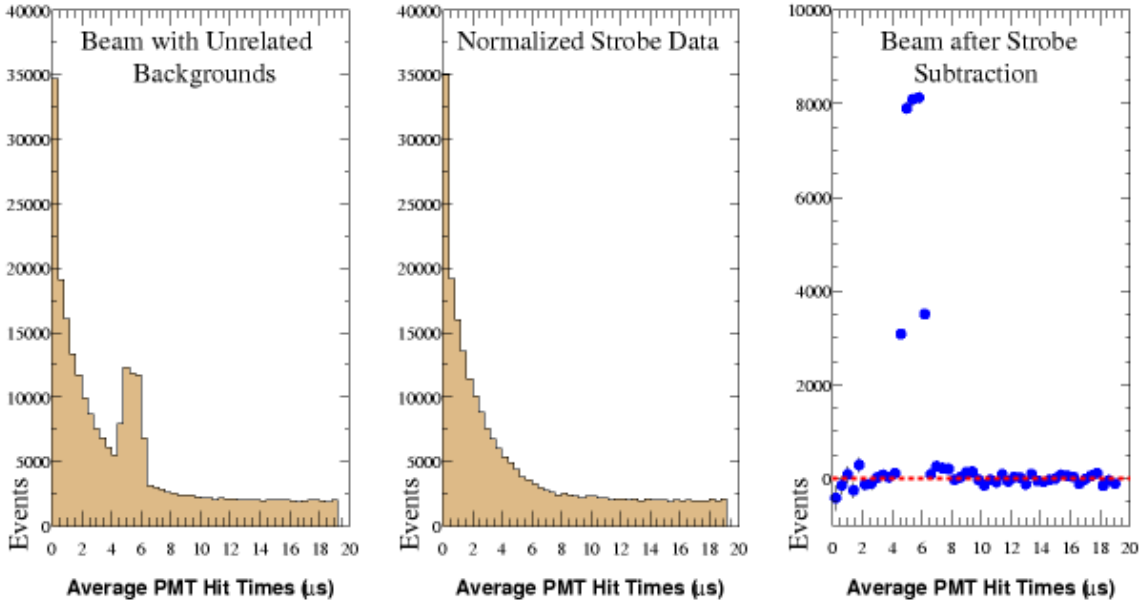
Low hit multiplicity, large scintillation fraction

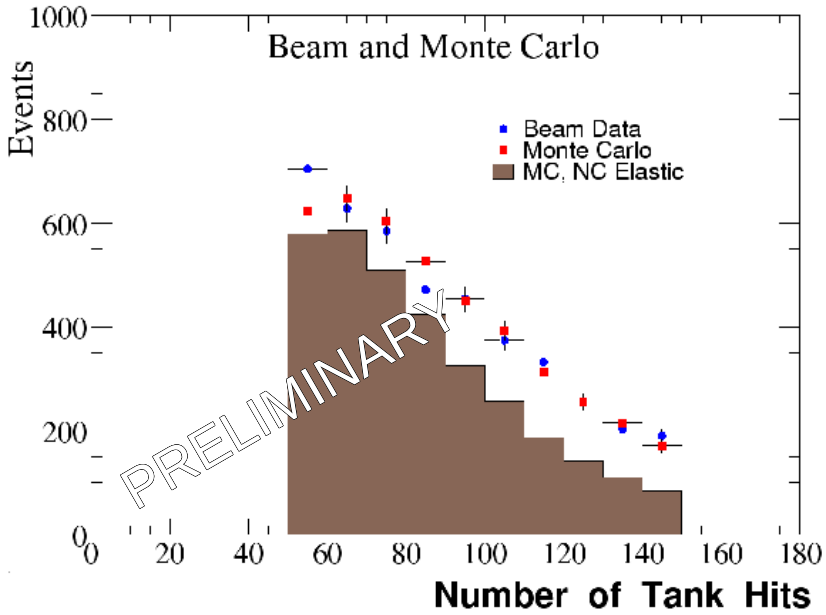
Large cross section (~17%)

Neutral Current Elastic Scattering

Background subtraction:

- Beam excess clearly visible for < 150 tank hits
- Non-beam background due to decay electrons environmental activity
- Subtract with random triggers ("strobe trigger")





Event selection:

$50 < N_{TANK} < 150$ (50 hit threshold for vertex fit)

Scintillation light fraction > 0.5

Normalize MC to events with $N_{TANK} > 50$

Reasonable agreement between data/MC for $N_{TANK} > 50$ with/without scintillation cut

Ongoing and Upcoming

Charged current quasi-elastic:
- compare with flux predictions
- ν_μ disappearance analysis
- probe low Q^2 region

Neutral current π^0 production:
- measure cross section
- analyze coherent contribution

Neutral current elastic:
- measure σ_{NC}/σ_{CC} vs. Q^2
- probe Δs

MiniBooNE has been collecting data for > 1 year
1.8 x 10^{20} protons on target
204K contained neutrino candidates

Detector working as expected

Reconstruction algorithms working well

Stay tuned for more!